Please cite this paper as follows: Saifuzzaman, M., Haque, M., Zheng, Z., Washington,S., 2015. Impact of mobile phone use on car-following behaviour of young drivers, Accident Analysis & Prevention, 82, 10-19.

Impact of mobile phone use on car-following behaviour of young drivers

Mohammad Saifuzzaman
Civil Engineering and Built Environment School,
Queensland University of Technology
2 George St GPO Box 2434, Brisbane QLD 4001, Australia
Email: m.saifuzzaman@qut.edu.au

Dr Md. Mazharul Haque
Centre for Accident Research and Road Safety (CARRS-Q),
Faculty of Health and Civil Engineering and Built Environment,
Science and Engineering Faculty,
Queensland University of Technology
2 George St GPO Box 2434, Brisbane QLD 4001, Australia
Email: m1.haque@qut.edu.au

Dr Zuduo Zheng (Corresponding author)
Civil Engineering and Built Environment School,
Queensland University of Technology
2 George St GPO Box 2434, Brisbane QLD 4001, Australia
Email: zuduo.zheng@qut.edu.au

Prof Simon Washington
Centre for Accident Research and Road Safety (CARRS-Q),
Faculty of Health and Civil Engineering and Built Environment,
Science and Engineering Faculty,
Queensland University of Technology
2 George St GPO Box 2434, Brisbane QLD 4001, Australia
Email: simon.washington@qut.edu.au

February 06, 2015

ABSTRACT

Multitasking, such as the concurrent use of a mobile phone and operating a motor vehicle, is a significant distraction that impairs driving performance and is becoming a leading cause of motor vehicle crashes. This study investigates the impact of mobile phone conversations on car-following behaviour. The CARRS-Q Advanced Driving Simulator was used to test a group of young Australian drivers aged 18 to 26 years on a car-following task in three randomised phone conditions: baseline (no phone conversation), hands-free and handheld. Repeated measure ANOVA was applied to examine the effect of mobile phone distraction on selected car-following variables such as driving speed, spacing, and time headway. Overall, drivers tended to select slower driving speeds, larger vehicle spacings, and longer time headways when they were engaged in either hands-free or handheld phone conversations, suggesting possible risk compensatory behaviour. In addition, phone conversations while driving influenced car-following behaviour such that variability was increased in driving speeds, vehicle spacings, and acceleration and decelerations. To further investigate car-following behaviour of distracted drivers, driver time headways were modelled using Generalized Estimation Equation (GEE). After controlling for various exogenous factors, the model predicts an increase of 0.33 seconds in time headway when a driver is engaged in hands-free phone conversation and a 0.75 seconds increase for handheld phone conversation. The findings will improve the collective understanding of distraction on driving performance, in particular car following behaviour which is most critical in the determination of rear-end crashes.

Keywords: Car-following, mobile phone use while driving, distraction, driver behaviour, risk compensation

1. INTRODUCTION

1.1. Distracted driving induced by mobile phone use

Driver distraction can be defined as a diversion of attention away from activities critical for safe driving to a competing activity (Lee *et al.* 2009). *Distraction* is also described as multi-task driving which reduces attention and cognitive resources allocated to the driving task. Studies have shown that multitasking while driving deteriorates driving performance, increases reaction time, and impacts lateral lane position and vision. This, in turn, poses serious safety concerns on the roads. A naturalistic driving study with 43000 hours of driving data from 241 drivers showed that the use of mobile phone while driving is associated with a higher number of crashes and incidents than driver interactions with any other source of distraction (Neale *et al.* 2005).

An extensive literature has empirically documented the risks associated with mobile phone use while driving (see Drews and Strayer (2009) for a detail review). Driving with phone conversation is considered as multitasking where a part of brain is occupied for the processing of the auditory sentences. An analysis using functional magnetic resonance imaging (fMRI) showed that, mobile phone distraction requiring the processing of auditory sentences decreases the brain activity by as much as 37% of the critical tasks associated with driving (Just *et al.* 2008). The increased cognitive load might cause a withdrawal of attention from the visual scene where not all the information a driver sees is processed; this phenomena is known as inattention blindness (Strayer *et al.* 2003).

Mobile phone use while driving is one of the most common distractions that motor vehicle drivers engage. In 2012 the National Highway Transportation Safety Administration estimates that 9% of drivers on the roadway at any given daylight moment are using some type of phone (either handheld or hands-free); for handheld phone use in particular, this estimate was 5% (NHTSA 2014). White *et al.* (2010) observed 796 Australian drivers aged 17–76 years who owned mobile phones, and found that 43% of them reported answering calls while driving on a daily basis, followed by making calls (36%), reading text messages (27%), and sending text messages (18%). Mobile phone use while driving is more prevalent among young (and less experienced) drivers, who generally possess an elevated crash risk. A recent survey reported that almost one in two Australian drivers aged between

18 to 24 years used a handheld mobile phone while driving, nearly 60% of them sent text messages, and about 20% of them read emails and surfed the internet (AAMI 2012).

In a naturalistic driving study Fitch *et al.* (2013) investigated the effects of distraction from the use of mobile phones while driving on 204 drivers. On average drivers were estimated to be talking on a mobile phone 10.6 percent of the time when they were driving with a mean call duration of 4.02 minutes. The study identifies that mobile phone subtask (locating, answering, dialing, browsing, text messaging and ending the call) can take driver's eyes off the forward roadway for up to 33.1 to 71.5 percentage of time. Furthermore, locating/answering a handheld mobile phone was found to be associated with an increased safety risk (crash or near crash).

To reduce the negative effect of mobile phone use while driving, hands-free technology is widely used. However, conversation using both hands-free and handheld mobile phones has adverse effect on driving. A meta-analysis by Caird *et al.* (2008) reveals that the effect of hands-free versus handheld phone studies did not differ appreciably from one another in terms of reaction time of the driver. Overall, a mean increase in reaction time of 0.25 seconds was reported for all phone-related tasks. A recent simulator study reported that both hands-free and handheld phone conversations are associated with about 40% increase in reaction times of drivers to peripheral traffic events (Haque and Washington 2014). Overall, studies did not find any significant difference in relative risk of a crash for handheld and hands-free phones, both options individually associated with a fourfold increase in crash risk (McEvoy *et al.* 2005).

1.2. Impact of distracted driving on car-following

A few studies specifically have targeted to capture the adverse effect of mobile phone use on car-following behaviour. Car-following refers to the behaviour of a driver to follow a leading vehicle longitudinally. It is the most common routine driving situation and an important requirement for the safe driving (see Saifuzzaman and Zheng (2014) for the latest review).

In a driving simulator study Alm and Nilsson (1995) observed the effects of hands-free mobile phone conversation on car-following behaviour. In their study, 40 participants drove a simulator vehicle for 80km where a total of 16 car-following events occurred randomly. The participants were randomly exposed to a phone conversation task in 8 of these car-following situations. They observed an increased reaction time for phone conversation while driving. Furthermore, the participants did not compensate for their increased reaction time by increasing their headway during the phone task. However, later studies reported reduction in speed when driving with phone conversation, a behaviour known as risk compensation (Törnros and Bolling 2006). For example, Ranney *et al.* (2004) observed higher reduction of speed when driving with handheld phone conversation compared to other types of phone conversations (headset hands-free and voice dialing speaker kit hands-free) and baseline (no phone). Furthermore, drivers were found to increase their time headways during all types of phone conversations.

Drews and Strayer (2009) in their detail review about effect of mobile phone use on driving also reported increased reaction time and reduction of speed. Furthermore, an increase in lane deviation and fluctuation of speed are also reported which indicates less control over driving due to distraction caused by mobile phone use. A recent study by Stavrinos *et al.* (2013) also supports these findings by reporting significantly greater variability in driving speed, lower lane change frequency and higher lane deviations in distracted driving compared to baseline (no phone use while driving).

Strayer *et al.* (2011) in their study asked the participants to follow a pace car that was programmed to brake at 32 randomly distributed locations over a 24-mile multi-lane highway. They observed a slower brake reaction time for driver with mobile phone conversation compared to no phone driving. The distracted drivers also took longer time to recover their speed that was lost following braking. The drivers conversing on mobile phones tended to have a more cautious driving profile in terms of speed and following distance (i.e. maintaining lower speed and higher spacing) than non-distracted driving. However, crash rate was still higher compared to driving with no phone conversation. No significant difference was observed between driving with handheld and hands-free phone conversations.

Driver reaction time, speed, and following distance are considered key variables in describing the stability and flow of traffic. Driver engaging in phone conversations while driving can significantly influence these variables, thus, performs poorly in following the preceding vehicle. Although aforementioned studies have attempted to document the risk of mobile phone use in car-following situation, overall the literature is scarce, and our understanding on this important issue remains elusive. For instance, fluctuations in speed and spacing and acceleration noise have been seldom measured, which could give valuable insight about driver's control over car-following in distracted situations. Driver demographics could also influence car-following behaviour in distracted situation, which needs to be explored.

1.3. Research objective

This study aims to investigate the effect of both hands-free and handheld mobile phone conversation on car-following behaviour of young drivers. A simulator experiment was designed where a participant drove a simulator vehicle in three different phone conditions: baseline (no-phone conversation), hands-free phone conversation and handheld phone conversation. A wide range of variables (such as driving speed, spacing, speed difference, time headway and acceleration noise) were considered to examine car-following behaviour of distracted drivers. The effects of distraction on the car following behaviour were mainly identified by comparing the driving performances in distracted and non-distracted (no-phone conversation) conditions. In addition, driver's time headway was modelled using the Generalized Estimation Equation (GEE) to develop further insights into the car-following behaviour of distracted drivers.

2. DRIVING SIMULATOR EXPERIMENT

2.1. Driving simulator

To accomplish this study, an experimental driving simulator study was conducted at the Centre for Accident Research and Road Safety – Queensland (CARRS-Q), Queensland University of Technology (QUT). In this experiment a group of distracted drivers were exposed to a number of traffic events using the CARRS-Q Advanced Driving Simulator[1].

The simulator incorporates a complete Holden Commodore vehicle with working controls and instruments. When seated in the simulator vehicle, the driver and passengers are immersed in a virtual environment that includes a 180 degree front field of view (using three front-view projectors),

[1]Detail about the simulator can be found at http://www.carrsq.qut.edu.au/simulator/

simulated rear view mirror images, surround sound for engine and environment noise, real car cabin and simulated vehicle motion. Road images are displayed onto the front view projector, the wing mirrors and the rear view mirror at 60 Hz to create a photorealistic virtual environment. The simulator was capable of accurately reproducing motion cues for sustained acceleration, braking manoeuvers, cornering and interaction with varying road surfaces. The simulator used SCANeR™ studio software. Driving performances data like position, speed, acceleration and braking were recorded at rates up to 20 Hz.

2.2. Participants

Thirty-two volunteers were recruited by disseminating recruitment flyers using university student email addresses or university social media and distributing recruitment flyers inside the campus. An eligible participant should meet the following conditions: 1) be aged between 18 and 26 years, 2) hold either a provisional or open Australian issued driver's licence, 3) not had a history of motion sickness and epilepsy, and 4) not be pregnant. The participants were reimbursed upon completion of the study. The participants also filled a survey questionnaire about their driving history, mobile phone use, and driving behaviour.

Descriptive statistics of the participants are presented in Table 1. The participants were on average 21.47 (SD 1.98) years old and split evenly by gender. About 66% of the participants held open (non-restricted) licenses and the rest have provisional licenses. Note that in Queensland, Australia, a newly licensed driver is required to hold a provisional license for up to 3 years before obtaining an open license. Average driving experience was 4.2 (SD 1.87) years where the provisional and open license holders had 2.64 (SD 0.75) and 5.01 (SD 1.79) years of average driving experience, respectively. In terms of vehicle kilometre travelled about 44% drove less than 10,000km, 47% drove in between 10,000 to 20,000km, and the rest drove more than 20,000km in a typical year.

Table 1 also presents the mobile phone use history of the participants. On average a participant made (or received) 65 (SD 43) calls and sent (or received) 261 (SD 199) text messages in a typical week. More interestingly, the scenario about mobile phone uses while driving showed that, about 34% of the sample used it at least once in a day; 47% of used once or twice in a week; and the rest used mobile phones while driving only once or twice in a month or year. About the type of mobile phone use while talking and driving 53% of the participants reported using a hand-held phone 0–25% of the time, 19% reported 25–50%, 12% reported 50–75%, and the remaining 16% reported using a handheld phone 76–100% of the talking time whilst driving.

Table 1: Descriptive statistics of the participants

Driver characteristics	Mean	SD	Count	Percentage
Driver's age (years)	21.47	1.98	-	
Gender				
Male	-	-	16	50.00
Female	-	-	16	50.00
License type				
Open	-	-	21	65.63
Provisional	-	-	11	34.38
Years of driving	4.20	1.87	-	
Kilometres driven in a typical year				
0–10,000 km	-	-	14	43.75
10,000–20,000 km	-	-	15	46.88
>20,000 km	-	-	3	9.38
General mobile phone usage history				
Calls (in a typical week)	65.34	43.41		
Text message (in a typical week)	260.66	198.66		
Frequency of mobile phone use while driving				
at least once in a day	-	-	11	34.38
once or twice in a week	-	-	15	46.88
once or twice in a month or year	-	-	6	18.75
Usage of handheld phone while talking and driving				
0-25%	-	-	17	53.13
26-50%	-	-	6	18.75
51-75%	-	-	4	12.50
76-100%	-	-	5	15.63

2.3. Experimental setup

The simulated route in the experiment was 7km long that went through Brisbane CBD (central business district of Brisbane, Australia) and a hypothetical suburban area. Various traffic events were programmed to occur in the course of the simulated driving such as car-following, overtaking, pedestrian crossing and sudden breaking of a lead vehicle. A part of the experimental data has been used in Haque and Washington (2013) and Haque and Washington (2014) to observe the effect of distraction on reaction time. However, in this study the data from car-following event is used which has not been applied before[2]. Details of the participant testing protocol can be found in Haque and Washington (2014).

The car-following event was occurred along urban roads, where the speed limit was 40 km/h. A detail of the car-following scenario is shown in Figure 1. The odd number in this figure represents intersection and the even number represents the roadway between two intersections. The roadway has four lanes with unidirectional traffic flow. Lane 1 and lane 4 had parked vehicles, leaving only lane 2 and lane 3 available for driving.

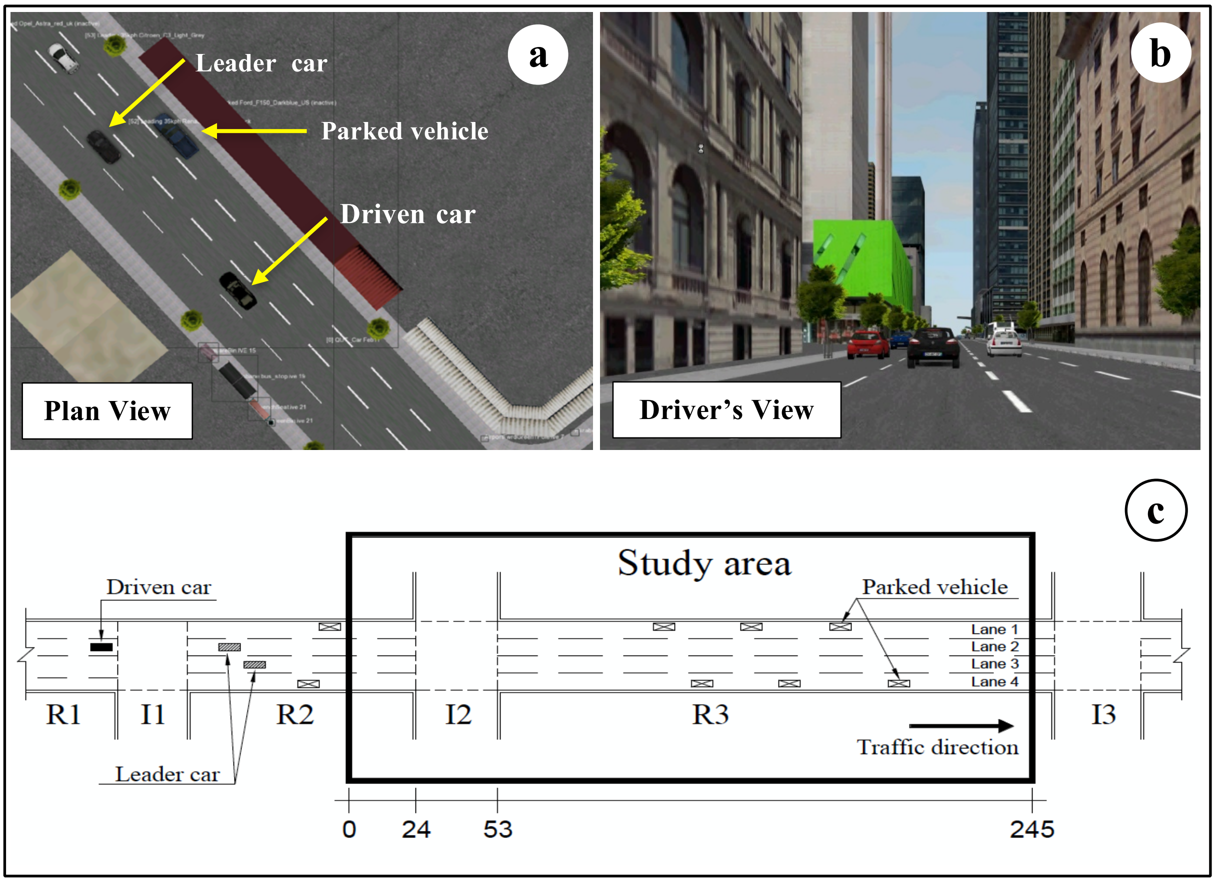


FIGURE 1 Details of car-following event: (a) plan view showing driven and leader vehicles; (b) driver's view showing leader vehicles and occupied adjacent lanes; (c) detail of the study area.

In this car-following scenario, when the driven vehicle (shown as the black rectangle in Figure 1) stops at the signalized intersection I1, two lead vehicles appear on the two lanes of road section R2

[2] The data used by Haque and Washington (2014) covered the traffic event where a pedestrian entered a zebra crossing from the sidewalk. Haque and Washington (2013) used data from the traffic event where a lead car breaks suddenly. In contrast, the data used in this paper were collected from a different road segment which was designed for the car-following event only. In addition, the methodology applied in this paper differs from those in the past two studies.

(shown as rectangle with hatched lines). They were pre-programmed with selected speeds. When the signal at the intersection I1 turns green, the two lead vehicles start moving slowly at same speed. No other cars were present in between the driven vehicle and the lead vehicles. Driven vehicle will be referred as subject vehicle in rest of this paper. When the spacing between the subject and the lead vehicle reached 60m, the speed of both lead vehicles increased up to 20km/h. When the spacing was 30m or less, lead vehicles increased the speed to 35km/h with an acceleration of about 4.0 m/s^2 and maintained that speed until the end of the car-following event. Both lead vehicles run with same speed so that the driver neither could overtake nor benefit by changing lane. The signal at intersection I2 was kept green to provide uninterrupted flow from section R2 to R3.

Each participant was required to drive in three phone conditions: a baseline condition (without any phone conversation), and hands-free and handheld phone conditions on the same road. Three route starting points were designed to reduce learning effects. The driving conditions were counterbalanced across participants to control for carry-over effects. Before participating in the experimental drive, each participant performed a practice drive of 5-6 minutes to become familiar with the driving simulator. The participants in this study did not go through acuity or colour deficiency testing. The details of the participant testing protocol can be found in Haque and Washington (2014).

2.4. Mobile phone task

A Nokia 500 phone was used in this study, which had dimensions of 111.3 x 53.8 x 14.1mm. The participants talked through a Bluetooth headset in the hands-free condition, and were required to hold the phone to their ear for the duration of the conversation in the handheld condition. The experimenter called the participant before the start of the drive and the call continued until the end of the drive. The experimenter was neither able to observe the driving of a participant, nor receive any clues regarding route progress.

The phone conversation was cognitive in nature, which required simultaneous storage and processing of information, and thus distracted the drivers by increasing their cognitive load. Conversation dialogues were modified from Burns *et al.* (2002). The participants were required to provide an appropriate response after hearing a complete question, solving a verbal puzzle, or solving a simple arithmetic problem.

3. DATA AND ANALYSIS

3.1. Dataset for analysis

There was no geographically fixed point where the car-following started, as it depended on the speed of the subject vehicle. To observe car-following behaviours from all the participants, a roadway segment of 245m length was selected as shown with a thick border in Figure 1. The car-following duration within the study area is ranged between 22 to 39 seconds. Similar length of the CF duration is reported in the literature (e.g., Muhrer and Vollrath, 2011; and He et al., 2014).

The final dataset contained vehicle trajectory data for 32 participant drivers in three phone conditions. Hence, a total of 96 car-following trajectories were obtained from the simulator experiment. The simulator recorded different driving related variables such as speed of the subject vehicle, spacing between the subject and the lead vehicle in the same lane of the driver, position of the vehicles, acceleration and braking of the subject vehicle, and speed difference between the subject and the lead vehicle. Driver demographic variables like age, gender, licence type, and driving history were collected from the questionnaire filled up by each participant before starting the simulator drives

3.2. Statistical analysis

A wide range of car-following related variables is identified in literature. The following variables were considered to examine the effect of distraction on car-following behaviour:

a) Average speed of the subject vehicle *n* [$\mu(V_n)$],
b) Average spacing from the lead vehicle [$\mu(\Delta X_n)$],
c) Average speed difference [$\mu(\Delta V_n)$, $\Delta V_n = V_{n-1} - V_n$],
d) Average time headway [$\mu(\Delta T_n)$, $\Delta T_n = \Delta X_n / V_n$],
e) Fluctuation in speed [$\sigma(V_n)$],
f) Fluctuation in spacing [$\sigma(\Delta X_n)$],
g) Acceleration noise.

Acceleration noise (AN) is the least used variable among the above mentioned ones. Acceleration noise is defined as the standard deviation of acceleration/deceleration of a vehicle. It was first proposed by Herman *et al.* (1959) to describe the driver–car–road interaction under diverse conditions. In free flowing traffic and in steady driving acceleration noise is relatively small. However, it may increase for various reasons for example when the roadway conditions deteriorate, and the level of traffic and congestion increases (Taylor et al. 2000). A reckless driver, who drives fast and applies sudden breaks, will have a larger acceleration noise than the one who drives smoothly (Jones and Potts, 1962). Farah et al. (2012) used acceleration noise to see if drivers' acceleration behaviours have improved when driving with cooperative systems. Belzet al. (2011) found that young drivers (i.e., 21-35years) have higher acceleration noise than old drivers (i.e., above 70 years old) in high speed and on grades. Studies (e.g., Jones and Potts, 1962) suggest that higher acceleration noise indicates potentially dangerous situations.

The above-mentioned variables were calculated for each driver in three driving situations. The dataset represents a panel data where each variable was measured in three different driving conditions. One-way repeated measures ANOVA test was performed to observe the effect of distraction on selected dependent variables. Later, a pairwise t-test with adjusted *p*-value was used as post hoc test to see which driving conditions were significantly different. Holm–Bonferroni (Holm 1979) method had been applied for *p*-value adjustment.

Finally, Generalized Estimation Equation (GEE) (Liang and Zeger 1986) was applied to model driver's time headway as a function of various independent variables. GEEs represent an extension of the Generalized Linear Models (GLM; Nelder and Baker 1972) to accommodate correlated data where the correlation is a result of repeated observations of the same participant. GLM is based on the maximum likelihood theory (McCullagh and Nelder, 1989) for independent observations. GEE is based on quasi-likelihood theory (Wedderburn, 1974) where no assumption needs to be made about the distribution of the response observations, and the response observations do not necessarily have to be independent. In the context of this study, time headways of the same driver were observed in three phone conditions, and hence GEE is a suitable modelling technique to account for possible correlation arising from multiple observations across individuals. While the GEE analysis can accommodate various correction structures, this study adopted an exchangeable correlation structure which assumes a constant correlation coefficient among multiple observations from an individual.

Since GEE models are particularly suitable for panel data where residuals are not independent, common likelihood based methods and other measures of model fit of ordinary linear regression are not applicable here. Pan (2001) proposed quasi-likelihood under independence model criteria (QIC) to select best working correlation structure. Zheng (2000) introduced a simple extension of R^2 statistics for GEE models and named as Marginal R^2 to be used as a fitness measure. In this study, the QIC and Marginal R^2 value were used to measure goodness of fit of the model.

4. RESULTS

4.1. Driving performances of distracted drivers in car-following situation

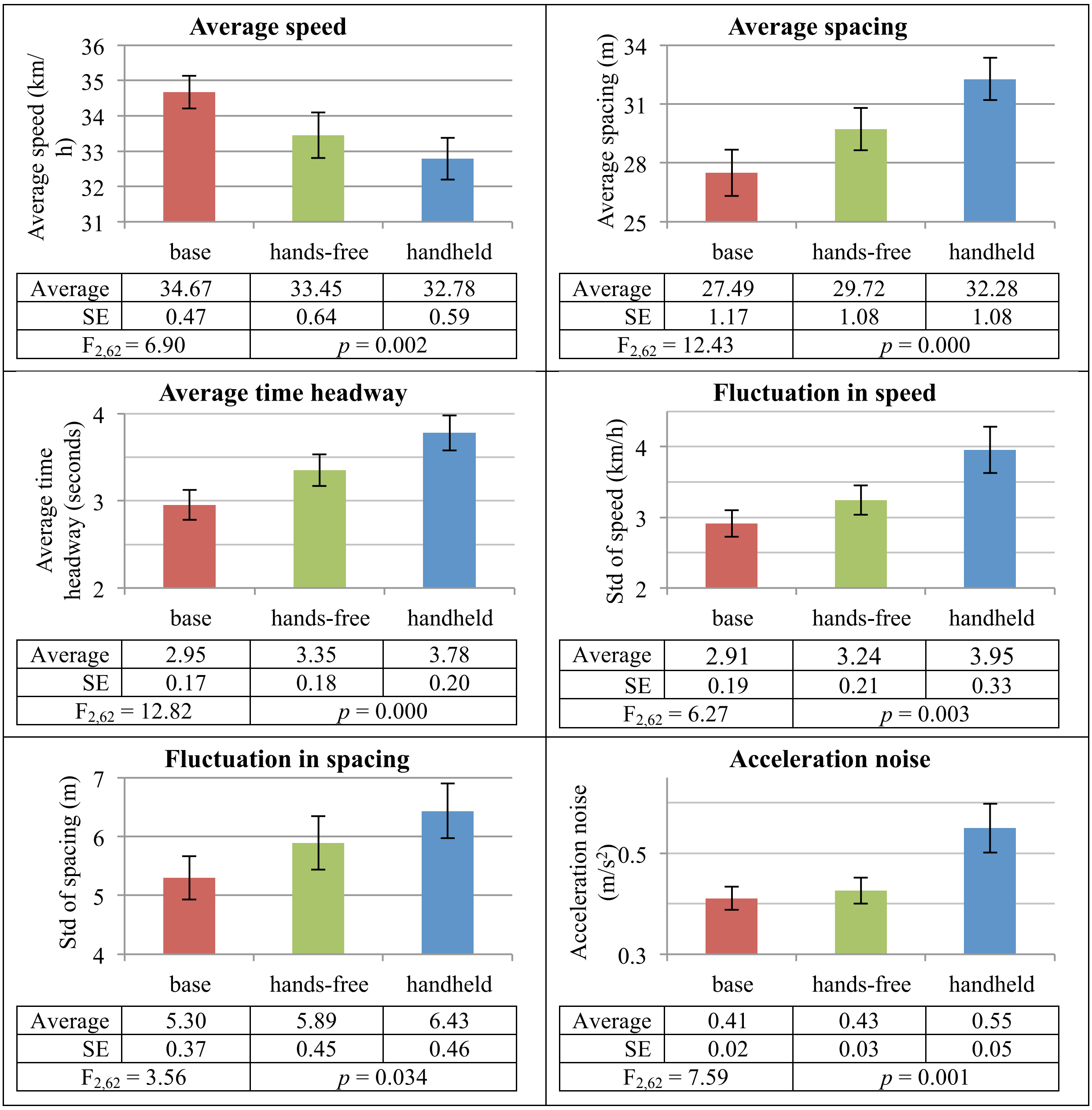
To examine the effect of mobile phone use while car-following, bar chart with mean value and standard error (SE) for selected CF variables are presented in Figure 2.

Average speed

It is the average of speeds obtained from car-following trajectories. Figure 2 shows that the average speed of the subject vehicle reduces with distraction level. A significant effect of distraction on speed selection is found from the repeated measures ANOVA test ($F_{2,62}=6.90$, $p=0.002$). Post hoc test further suggests that the difference in baseline vs. handheld phone condition is most significant ($p=0.004$) and baseline vs. hands-free are least significant ($p=0.029$). In general the average speed was 5.5% and 3.5% slower from baseline when drivers were distracted by a handheld and hands-free phone conversation respectively.

Average spacing

Average spacing is the mean distance the subject vehicle maintained from the lead vehicle while car-following. A significant increase in spacing choice is observed as an effect of distraction ($F_{2,62}=12.43$, $p=0.000$). Average spacing was 17.4% ($p=0.000$) higher in handheld and 8.1% ($p=0.045$) higher in hands-free compared to baseline condition.



Average speed

	base	hands-free	handheld
Average	34.67	33.45	32.78
SE	0.47	0.64	0.59
$F_{2,62} = 6.90$	$p = 0.002$		

Average spacing

	base	hands-free	handheld
Average	27.49	29.72	32.28
SE	1.17	1.08	1.08
$F_{2,62} = 12.43$	$p = 0.000$		

Average time headway

	base	hands-free	handheld
Average	2.95	3.35	3.78
SE	0.17	0.18	0.20
$F_{2,62} = 12.82$	$p = 0.000$		

Fluctuation in speed

	base	hands-free	handheld
Average	2.91	3.24	3.95
SE	0.19	0.21	0.33
$F_{2,62} = 6.27$	$p = 0.003$		

Fluctuation in spacing

	base	hands-free	handheld
Average	5.30	5.89	6.43
SE	0.37	0.45	0.46
$F_{2,62} = 3.56$	$p = 0.034$		

Acceleration noise

	base	hands-free	handheld
Average	0.41	0.43	0.55
SE	0.02	0.03	0.05
$F_{2,62} = 7.59$	$p = 0.001$		

FIGURE 2 Effect of distraction on different traffic flow parameters (error bar represents SE).

Average speed difference

It is the mean speed difference between the subject and lead vehicle during the car-following event. No significant difference is observed in average speed difference ($F_{2,62}=0.51$, $p=0.604$), and standard deviation of speed difference ($F_{2,62}=1.90$, $p=0.158$) in distracted situation. A driver in car-following situation continuously attempts to match their speed with the lead vehicle. Hence, it is expected that the speed difference would be similar in all three driving conditions.

Average time headway

Time headway for driver *n* at an instant *t* is defined as the elapsed time between the front of the lead vehicle passing a point on the roadway and the front of the following vehicle passing the same point (Evans 1991). A significant effect of distraction on average time headway during car-following is observed ($F_{2,62}=12.82$, $p=0.000$). The mean values suggest that time headway increases with distraction level. Compared to baseline condition the average time headway was 28.0% ($p=0.000$) higher for handheld and 13.5% ($p=0.018$) for hands-free phone conversation while driving.

Fluctuation in speed

It is the standard deviation of speed of the driven vehicle during car-following. A significant effect of distraction on fluctuation in speed is observed ($F_{2,62}=6.27$, $p=0.003$). The mean suggest that fluctuation in speed increases with distraction level. The fluctuation in speed was 35.9% ($p=0.022$) higher when driving with handheld phone conversation compared to baseline condition. The difference between hands-free and baseline was not statistically significant ($p=0.232$).

Fluctuation in spacing

It is the standard deviations of spacing between the subject and lead vehicle during car-following. Similar to fluctuation in speed, a significant effect of distraction on fluctuation in spacing is observed ($F_{2,62}=3.56$, $p=0.034$). Figure 3 suggests that fluctuation in spacing increases with distraction level. The fluctuation in spacing was 21.5% ($p=0.023$) higher when driving with handheld phone conversation compared to baseline. The difference between hands-free and baseline was not statistically significant ($p=0.378$).

Acceleration noise

It is the standard deviation of acceleration of the subject vehicle. A significant increase in acceleration noise is observed as an effect of distraction ($F_{2,62}=7.59$, $p=0.001$). The bar chart in Figure 3 and Post hoc test suggest that the distraction effect is not significant for hands-free driving ($p=0.557$), but acceleration noise was significantly higher (33.9%, $p=0.015$) when driving with handheld phone conversation compared to the baseline condition. Acceleration noise is an indicator of driving smoothness. An increased acceleration noise in handheld condition explains less control over driving.

4.2. Speed, spacing and time headway profile

To observe the car-following behaviour along the road segment, four most important car-following variables were considered. They were speed, spacing, time headway and speed difference. The average values of these variables were plotted against distance travelled. The variable values are averaged over every 4m segment (which is the size of the driven car) using the formula shown in Equation (1):

$$X_{ij} = \frac{1}{32}\sum_{1}^{n=32} X_{nij} \quad ; \quad where \begin{cases} i = segment\ id\ [1{:}\,61] \\ j = [base, handsfree, handheld] \end{cases} \tag{1}$$

where X denotes the variable value, i is the segment id and j is the phone condition. The profiles are shown in Figure 3.

The speed, spacing and time headway profile shows clear difference between the three driving conditions. In general, distracted drivers tend to select a slower driving speed and maintain a higher spacing and longer time headways with the lead vehicle throughout the length of the road where car-following situation existed. Maximum difference is observed between baseline condition and driving with handheld phone conversation. No clearly noticeable difference is observed in speed difference since drivers were exposed in a car-following situation. As a result, drivers appear to match their speed with the lead vehicle, which was maintaining a constant speed.

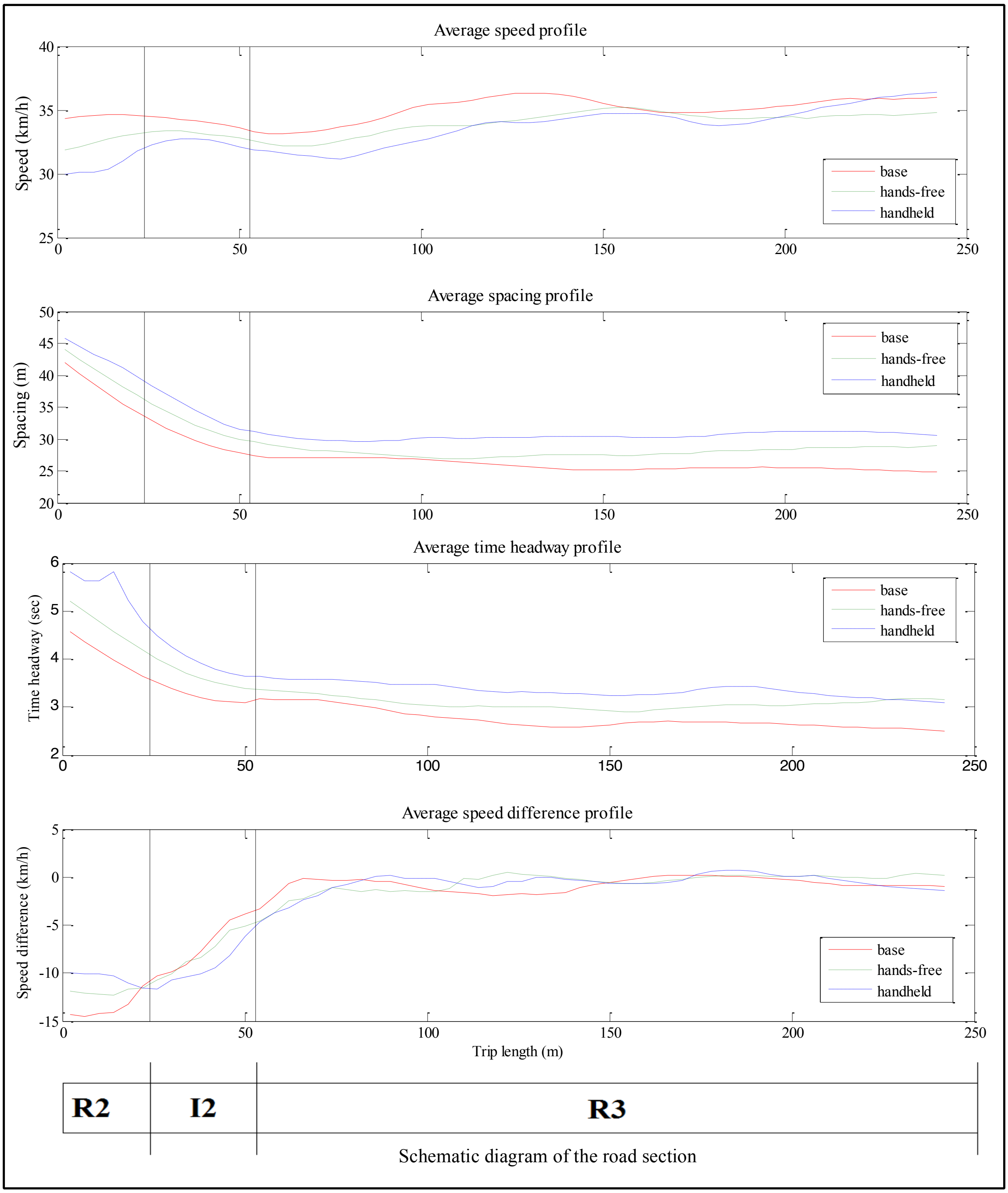


FIGURE 3 Profile for average speed, average spacing (ΔX), average time headway (ΔT) and average velocity difference (ΔV).

4.3. GEE analysis

GEE was applied to model driver's time headway as a function of various independent variables. The analysis will identify what factors may affect driver's time headway selection. Time headway was selected as the dependent variable because it considers both the speed and spacing together. The potential explanatory variables for the statistical model included phone condition, driver demographics (age, gender, licence type and driving experience) and average speed difference with the lead vehicle. Descriptive statistics of these variables are presented in Table 2. Data from all 32 drivers are available in three phone conditions, which created a balanced panel data with 3 observations per driver.

Table 2: Descriptive statistics of variables for GEE

Variable name	Description of variables	Min	Max	Average	SD	Count
Phone condition						
Base	No phone conversation = 1, otherwise = 0	-	-	-	-	32
Hands-free	Hands-free phone conversation = 1, otherwise = 0	-	-	-	-	32
Handheld	Handheld phone conversation = 1, otherwise = 0	-	-	-	-	32
Driver's age	Continuous variable	18	26	21.47	1.98	-
Gender						
Male	If a driver was male = 1, otherwise = 0	-	-	-	-	16
Female	If a driver was female = 1, otherwise = 0	-	-	-	-	16
License type						
Open	If a driver held an open license = 1, otherwise = 0	-	-	-	-	21
Provisional	If a driver held a provisional license = 1, otherwise = 0	-	-	-	-	11
Years of driving	Continuous variable	1	9	4.20	1.87	-
Average time headway	Continuous variable	1.23	6.36	3.36	1.10	-
Average speed difference	Continuous variable	-5.93	3.10	-2.46	1.68	-

Time headway selections of drivers were modelled with a Generalized Estimation Equation with exchangeable correlation structure. The model results are presented in Table 3. The best-fit model was derived from a set of models with all possible independent variables following Marginal R^2 and QIC criteria. This model produced the smallest QIC value from a set of alternative models with different independent variables and correlation structures. Smallest QIC value ensures the selection of best working correlation structure (exchangeable in this case). The model also estimated a value of 0.50 for the exchangeable correlation parameter, which indicates a significant correlation among observations of each driver and thus further ensures the appropriateness of the GEE model. This model produced highest Marginal R^2 value among the tested models. The Marginal R^2 value suggests that the model can explain 49% of the variability in the dataset. In this model, all parameters are significant. The best-fit model retained four significant variables including phone condition, average speed difference, driver gender and driver licence type.

The parameters for both phone conditions have been found to be positive and significant at 5% significance level in the GEE model. Results clearly indicate that distracted driving influences the time headway selection of drivers in car-following situation. Parameter estimates suggest that distracted drivers, on average, tend to keep 0.33 seconds more headways when engaged in hands-free phone conversation compared to baseline driving. The corresponding headway difference for handheld phone driving condition was about 0.75 seconds. The effects of distraction are higher in driving with handheld phone conversation since this condition has both cognitive and manual distraction. Consequently, handheld driving may be associated with the highest time headway among the three driving scenarios.

Table 3: GEE Model Estimates for Mean Time Headway.[ab]

Variable	Estimate	SE	Wald statistic	*p*-value
Constant	3.77	0.21	308.32	0.0000***
Phone Condition				
Hands-free	0.33	0.13	6.54	0.011*
Handheld	0.75	0.16	21.63	0.000***
Average speed difference	0.29	0.03	92.47	0.000***
Gender				
Female	-0.68	0.28	5.66	0.017*
Licence Type				
Provisional	0.81	0.30	7.24	0.007**
Estimated scale parameters (intercept)	0.61	0.11		
Estimated Correlation Parameters (alpha)	0.50	0.12		
QIC	-30.84			
Quasi-Likelihood	-29.47			
Marginal R^2	0.49			
Number of Observations	96			
Number of clusters	32			
Maximum cluster size	3			

Signif.codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

[a] Model equation: Average time headway = $b_0 + b_1$ * Phone condition + b_2 * Average speed difference + b_3 * Gender + b_4 * Licence type

Average speed difference, which represents the speed difference between the subject and lead vehicle, has also been significant and positive in the GEE model of time headways in car-following situation.

Results suggest that time headway increases with the increase in speed differences. A 1 km/h increase in speed differences leads to about 0.29 seconds increase in time headways. Speed difference can have both positive and negative values. When a lead vehicle is travelling faster than the subject vehicle, the speed difference is positive and the corresponding time headway increases. On the other hand, when the subject vehicle is approaching to a slower vehicle, the speed difference is negative and the corresponding time headway decreases.

It is interesting to notice that female drivers keep less time headway than male drivers. The parameter associated with gender suggests that in general female drivers keep 0.68 seconds less time headway than a male driver in same car-following situation. Driving experience seems to have an impact on time headway selection as the model shows that 'provisional' license holders (less experienced driver) prefer to keep longer time headway than 'open license holders (experienced driver). The effect is even higher than gender. According to the model, a provisional licence holder will keep 0.81 seconds longer time headway than an open licence holder in car-following situation. It is understandable as provisional drivers might have less confidence on their driving ability and thus drive with longer time headway.

5. DISCUSSION

Types of phone conversation (hands-free or handheld) affect the car following behaviour differently. When driving with hands-free phone conversation the car-following performance did not deteriorate significantly from the baseline. As a result no significant difference was observed for variables like average spacing, fluctuation in spacing and speed, and acceleration noise. This can be partially explained by the prevalence of mobile phone use among the young participants (on average the participants reported to make 65 calls and send 260 text messages in a typical week). However, similar tests on older drivers are needed to confirm this finding.

The findings were different for drivers engaged in handheld phone conversations, with the additional physical constraint of holding the phone. This multitasking configuration increased the workload to the highest level among the three phone conditions. The handheld condition placed an additional manual load on the driver, which together with the mental demand, leads to a greater distraction effect on drivers during the two phone conversations (Higher workload in handheld phone condition was also reported in Matthews et al. (2003) who discovered no difference in mental demand between hands-free and handheld phone conversation, however, physical demand was higher for handheld phone). As a result, the car-following performance was significantly deteriorated. The largest difference between driving conditions was the fluctuation in speed between handheld and baseline driving condition. The second largest difference was acceleration noise between the handheld and baseline conditions. Compared to the baseline condition, a 35.9% increase in speed fluctuation along with 33.9% increase in acceleration noise revealed a significant impact of distracted behaviour caused by handheld phone conversations. Increased fluctuation in speed and acceleration explains less control over driving situation in handheld situation compared to baseline. However, drivers have perceived the risk associated with distraction caused by phone conversation while driving. To compensate the risk they showed risk compensatory behaviour by increasing spacing and decreasing speed from baseline condition. The risk compensatory behaviour is observed in both phone conditions. However, the magnitude is highest for handheld phone conversation which is most likely caused by highest perception of risk in this situation.

Fluctuation of spacing increased when driving with handheld phone conversation compared to baseline. However, in Figure 3 the spacing profiles become fairly stable in all three conditions after about 70m from the start point of car-following. Additional descriptive analysis is performed on car-following data within 70-245m road section. The new analysis shows similar conclusion for all variables except that the difference in fluctuation of spacing becomes insignificant ($F_{2,62}=0.618, p=0.541$). It appears that distracted drivers have more variations in spacing when they try to achieve their desired spacing for car-following. Once the desired spacing is reached, drivers try to maintain that unless any change occurs in driving environment.

The time headway selection of drivers was modelled using GEE. The model shows that a typical driver increases the time headway by 0.33 seconds when conversing using hands-free devices and by 0.75 seconds when using handheld mobile phones. In general, female drivers maintain shorter time headways than male drivers. Less experienced drivers (provisional license holders) maintain greater time headways than experienced drivers (open license holder) on average. Female drivers with open driving licenses maintain the shortest time headways in this model, while male drivers with provisional licences maintain the longest time headways. Distraction further increases time headways for all drivers.

6. CONCLUSION

This study investigates car-following behaviour of drivers distracted by mobile phone conversations. Participants were exposed to a car-following task in a motion-based driving simulator where the lead vehicle maintained a predefined speed profile depending on the spacing between the driver and the lead vehicle. Focus was given to the behaviour of young drivers only with an age cohort between 18 to 26 years. The sample size was good enough to identify some patterns and factors affecting the car-following behaviour of young drivers, although a larger sample size my increase the statistical reliability of the results. A set of variables was selected to capture car-following behaviour. Repeated measures ANOVA tests were implemented to identify the effect of mobile phone distraction on the selected car-following variables. The study finds evidence of a significant effect of distraction on speed selection, vehicle spacing, and time headways. Overall, drivers maintained lower speeds, larger vehicle spacings, and longer time headways when engaged in phone conversations compared to baseline without phone conversations. This finding may indicate the presence of risk-compensatory behaviour, which has been elsewhere observed and reported in the literature (Ranney *et al.* 2004, Strayer *et al.* 2011).

The repeated measures ANOVA test also revealed significant effects of distraction on fluctuation in speed and spacing, and acceleration noise. These increases suggest that distracted driving results in less consistent control in maintaining speed and vehicle spacing in car-following situations. The reduction in speed and increase in vehicle spacing could reflect drivers' attempts to compensate for the increased risk associated with the mobile phone conversations, or could be an artefact of the distraction itself. If the reduction reflects risk compensation, there is insufficient evidence to assess whether the reduction in crash risk would offset the increased crash risk arising from distraction. Other evidence on crash risk while distracted suggests that crash risk overall is increased while distracted. For example, both hands-free and handheld phone uses while driving are associated with a fourfold increase in accident risk (McEvoy *et al.* 2005, Redelmeier and Tibshirani 1997). These findings suggest that observed risk compensation is insufficient to offset risk increment caused by cognitive distraction.

These results can foster a better understanding of the consequence of distracted driving on road crashes, and shed light on the complexity involved with modelling driving behaviour. Driving behaviour modelling is one of the oldest and most studied topics in Traffic Engineering. Many models have been developed to describe two primary driving tasks: car following (see Saifuzzaman and Zheng (2014) for the latest review) and lane changing (see Zheng (2014) for a comprehensive review). Despite notable progress in the last few decades on this important topic, efforts to incorporate human factor effects are limited. For most driving behaviour models, information on vehicular movements is the only input. The potential complexity introduced by human drivers is by and large ignored. This omission is not surprising due to our limited understanding on human factor issues. More specifically, there is a clear need to comprehensively investigate and accurately quantify how drivers perform when distracted because of its importance to both road safety and driver behaviour modelling. This research gap partially motivated this study. The findings clearly show that drivers behave differently when distracted by hand-held phone conversations. Unfortunately, most of the existing car-following models do not consider such impacts on driving because they are developed for normal (i.e., non-distracted) driving situations (Saifuzzaman and Zheng 2014). Recently, researchers in the traffic flow community have realized the importance of improved and more comprehensive reflection of human factor dimensions in car-following models, and have started exploring new ideas (e.g., Hamdar and Mahmassani (2008)). We believe that empirical evidence on how distracted driving influences car-following behaviour (e.g., speed, spacing, and time headway) revealed in this study can facilitate such efforts. In keeping, the authors are working currently on improving car-following model performance by incorporating behavioural differences caused by distraction.

Current study did not address reaction time differences arising from distracted driving, as this topic is covered in Haque and Washington (2013), and Haque and Washington (2014). This study is focused on car-following behaviour of young drivers only; further study is required to investigate the effect of mobile phone distraction in a wider range of driver ages to compare the car-following behaviour across different age groups. Future studies are also required to investigate distracted car-following behaviour in other scenarios, for example, on longer road section, with different speed limits, and on curve segments. Influence of other type of human factors (for example, fatigue, drowsiness, alcohol and drug use, emotion and stress) on car-following behaviour should also be investigated in future to obtain a better picture about human car-following behaviour in different circumstances.

Acknowledgements: The authors would like to acknowledge Mr. Andrew Haines for programming the simulator experiment, and thank three anonymous reviewers for their comments, which have improved this paper's quality. This research was partially funded by Queensland University of Technology.

REFERENCES

Aami, 2012. 11th aami young drivers index.Available from: http://www.aami.com.au/sites/default/files/fm/news/11th_aami_young_drivers_index.pdf.

Alm, H., Nilsson, L., 1995. The effects of a mobile telephone task on driver behaviour in a car following situation. Accident Analysis & Prevention 27 (5), 707-715.

Belz, N.P., Aultman-Hall, L., 2011. Analyzing the effect of driver age on operating speed and acceleration noise. Transportation Research Record: Journal of the Transportation Research Board 2265 (1), 184-191.

Burns, P., Parkes, A., Burton, S., Smith, R., Burch, D., 2002. How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol. TRL Report 547.

Caird, J.K., Willness, C.R., Steel, P., Scialfa, C., 2008. A meta-analysis of the effects of cell phones on driver performance. Accident Analysis & Prevention 40 (4), 1282-1293.

Drews, F.A., Strayer, D.L., 2009. Cellular phones and driver distraction. In: Regan, M.A., Lee, J.D., Young, K.L. eds. Driver distraction: Theory, effects, and mitigation. CRC Press, pp. 169-190.

Evans, L., 1991. Traffic safety and the driver Science Serving Society.

Farah, H., Koutsopoulos, H.N., Saifuzzaman, M., Kölbl, R., Fuchs, S., Bankosegger, D., 2012. Evaluation of the effect of cooperative infrastructure-to-vehicle systems on driver behavior. Transportation Research Part C: Emerging Technologies 21 (1), 42-56.

Fitch, G.M., Soccolich, S.A., Guo, F., Mcclafferty, J., Fang, Y., Olson, R.L., Perez, M.A., Hanowski, R.J., Hankey, J.M., Dingus, T.A., 2013. The impact of hand-held and hands-free cell phone use on driving performance and safety-critical event risk. Report No. DOT HS 811 757. National Highway Traffic Safety Administration, Washington, DC.

Hamdar, S.H., Mahmassani, H.S., 2008. From existing accident-free car-following models to colliding vehicles: Exploration and assessment. Transportation Research Record: Journal of the Transportation Research Board 2088 (1), 45-56.

Haque, M., Washington, S., 2013. Effects of mobile phone distraction on drivers' reaction times. Journal of the Australasian College of Road Safety 24 (3), 20-29.

Haque, M.M., Washington, S., 2014. A parametric duration model of the reaction times of drivers distracted by mobile phone conversations. Accident Analysis & Prevention 62, 42-53.

Herman, R., Montroll, E.W., Potts, R.B., Rothery, R.W., 1959. Traffic dynamics: Analysis of stability in car following. Operations research 7 (1), 86-106.

Holm, S., 1979. A simple sequentially rejective multiple test procedure. Scandinavian journal of statistics, 65-70.

He, J., Chaparro, A., Nguyen, B., Burge, R.J., Crandall, J., Chaparro, B., Ni, R., Cao, S., 2014. Texting while driving: Is speech-based text entry less risky than handheld text entry? Accident Analysis & Prevention 72, 287-295.

Jones, T.R., Potts, R.B., 1962. The measurement of acceleration noise-a traffic parameter. Operations Research 10 (6), 745-763.

Just, M.A., Keller, T.A., Cynkar, J., 2008. A decrease in brain activation associated with driving when listening to someone speak. Brain research 1205, 70-80.

Lee, J.D., Young, K.L., Regan, M.A., 2009. Defining driver distraction. In: Lee, J.D., Young, K.L., Regan, M.A. eds. Driver distraction: Theory, effects, and mitigation. CRC Press, pp. 31-40.

Liang, K.-Y., Zeger, S.L., 1986. Longitudinal data analysis using generalized linear models. Biometrika 73 (1), 13-22.

McCullagh, P., Nelder, J. A., 1989. Generalized Linear Models. 2nd ed. London: Chapman& Hall.

McEvoy, S.P., Stevenson, M.R., Mccartt, A.T., Woodward, M., Haworth, C., Palamara, P., Cercarelli, R., 2005. Role of mobile phones in motor vehicle crashes resulting in hospital attendance: A case-crossover study. BMJ 331, 428-430.

Muhrer, E., Vollrath, M., 2011. The effect of visual and cognitive distraction on driver's anticipation in a simulated car following scenario. Transportation Research Part F: Traffic Psychology and Behaviour 14 (6), 555-566.

Neale, V.L., Dingus, T.A., Klauer, S.G., Sudweeks, J., Goodman, M., 2005. An overview of the 100-car naturalistic study and findings. National Highway Traffic Safety Administration, Paper no 05-0400.

Nelder, J.A., Baker, R., 1972. Generalized linear models John Wiley & Sons.

NHTSA, 2014. Driver electronic device use in 2012. Traffic Safety Facts. Paper No. DOT HS 811884. National Highway Traffic Safety Administration, Washington, DC.

Pan, W., 2001. Akaike's information criterion in generalized estimating equations. Biometrics 57 (1), 120-125.

Redelmeier, M.D., Tibshirani, R.J., 1997. Association between cellular-telephone callsand motor vehicle collisions. New England Journal of Medicine 336 (7), 453-458.

Ranney, T., Watson, G., Mazzae, E.N., Papelis, Y.E., Ahmad, O., & Wightman, J.R., 2004. Examination of the distraction effects of wireless phone interfaces using the National Advanced Driving Simulator-Preliminary report on freeway pilot study. Paper No. DOT 809 737. National Highway Transportation Safety Administration: East Liberty, OH.

Saifuzzaman, M., Zheng, Z., 2014. Incorporating human-factors in car-following models: A review of recent developments and research needs. Transportation Research Part C: Emerging Technologies 48, 379-403.

Schömig, N., Metz, B., Krüger, H.-P., 2011. Anticipatory and control processes in the interaction with secondary tasks while driving. Transportation Research Part F: Traffic Psychology and Behaviour 14 (6), 525-538.

Stavrinos, D., Jones, J.L., Garner, A.A., Griffin, R., Franklin, C.A., Ball, D., Welburn, S.C., Ball, K.K., Sisiopiku, V.P., Fine, P.R., 2013. Impact of distracted driving on safety and traffic flow. Accident Analysis & Prevention 61, 63-70.

Strayer, D.L., Cooper, J., Drews, F.A., 2011. Profiles in cell phone-induced driver distraction.

Strayer, D.L., Drews, F.A., Johnston, W.A., 2003. Cell phone-induced failures of visual attention during simulated driving. Journal of experimental psychology: Applied 9 (1), 23.

Taylor, M.A.P., Woolley, J.E., Zito, R., 2000. Integration of the global positioning system and geographical information systems for traffic congestion studies. Transportation Research Part C: Emerging Technologies 8 (1), 257-285.

Törnros, J., Bolling, A., 2006. Mobile phone use–effects of conversation on mental workload and driving speed in rural and urban environments. Transportation Research Part F: Traffic Psychology and Behaviour 9 (4), 298-306.

Wedderburn, R. W. M. (1974). Quasi-likelihood functions, generalized liner models, and the Gauss-newton method. Biometrika 61, 439–447.

White, K.M., Hyde, M.K., Walsh, S.P., Watson, B., 2010. Mobile phone use while driving: An investigation of the beliefs influencing drivers' hands-free and hand-held mobile phone use. Transportation Research Part F: Traffic Psychology and Behaviour 13 (1), 9-20.

Zheng, B., 2000. Summarizing the goodness of fit of generalized linear models for longitudinal data. Statistics in medicine 19 (10), 1265-1275.

Zheng, Z., 2014. Recent developments and research needs in modeling lane changing. Transportation Research Part B: Methodological 60, 16-32.